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(54) **COMMUNICATION WITH LIGHTING UNITS OVER A POWER BUS**

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(51) **Int. Cl.**

H05B 37/02	(2006.01)
G05B 11/01	(2006.01)
H05B 33/08	(2006.01)

(52) **U.S. Cl.**

CPC ***G05B 11/01*** (2013.01); ***H05B 33/0851*** (2013.01); ***H05B 37/0263*** (2013.01)

(58) **Field of Classification Search**

CPC H04B 2203/5416

USPC 315/240, 297, 311; 340/310.12; 323/369, 364, 353, 354

See application file for complete search history.

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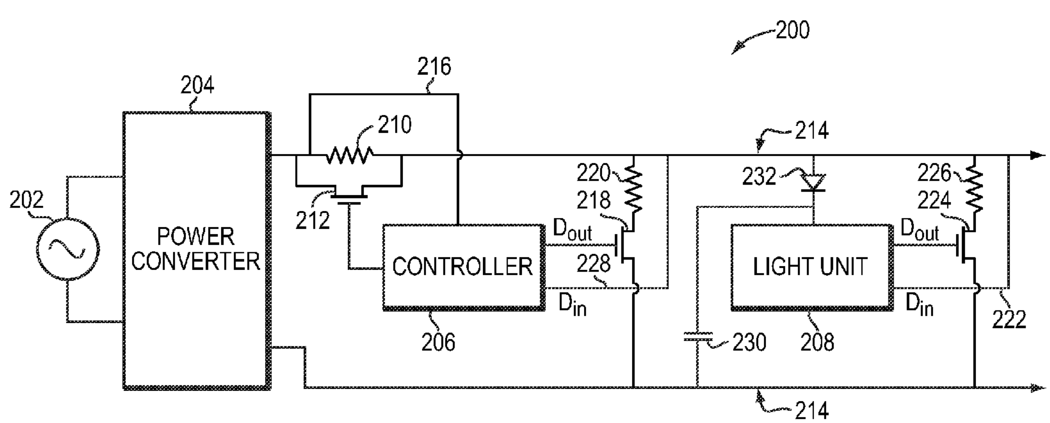
(57) **ABSTRACT**

A first entity communicates with a second entity over a shared power bus by switching the bus to a high-impedance state and modifying the voltage on the power bus, in accordance with an outgoing communication, such that the modified voltage is detected by the second entity and the communication is received thereto.

19 Claims, 9 Drawing Sheets



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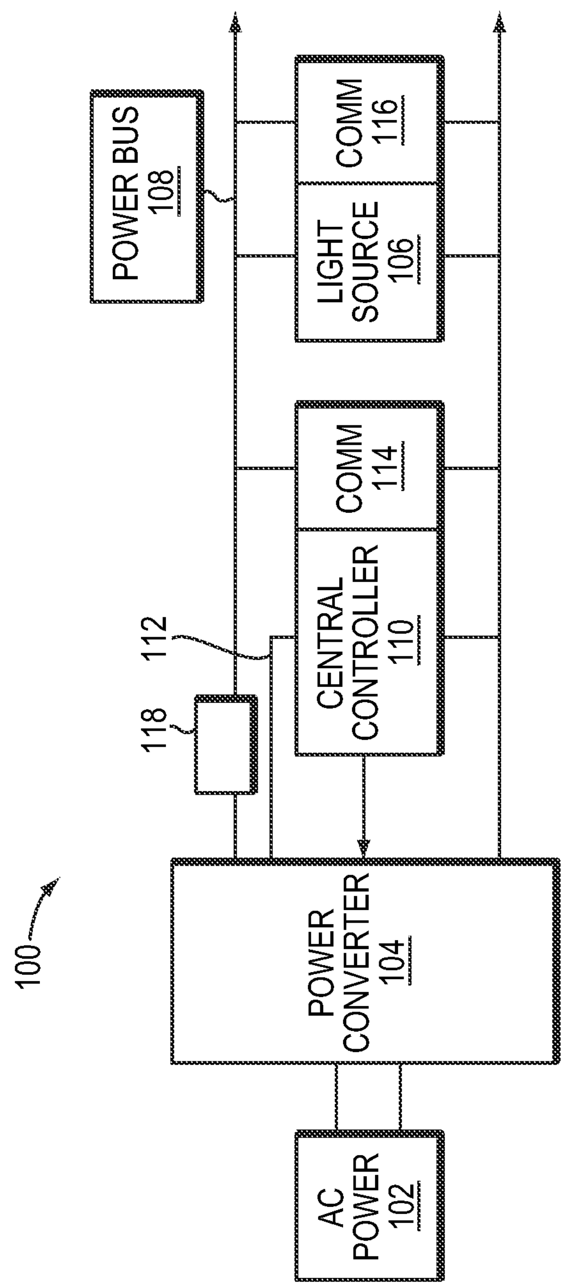

100
AC POWER 102
POWER CONVERTER 104
LIGHT SOURCE 106
POWER BUS 108
CENTRAL CONTROLLER 110
112
COMM 114
COMM 116
118

FIG. 1

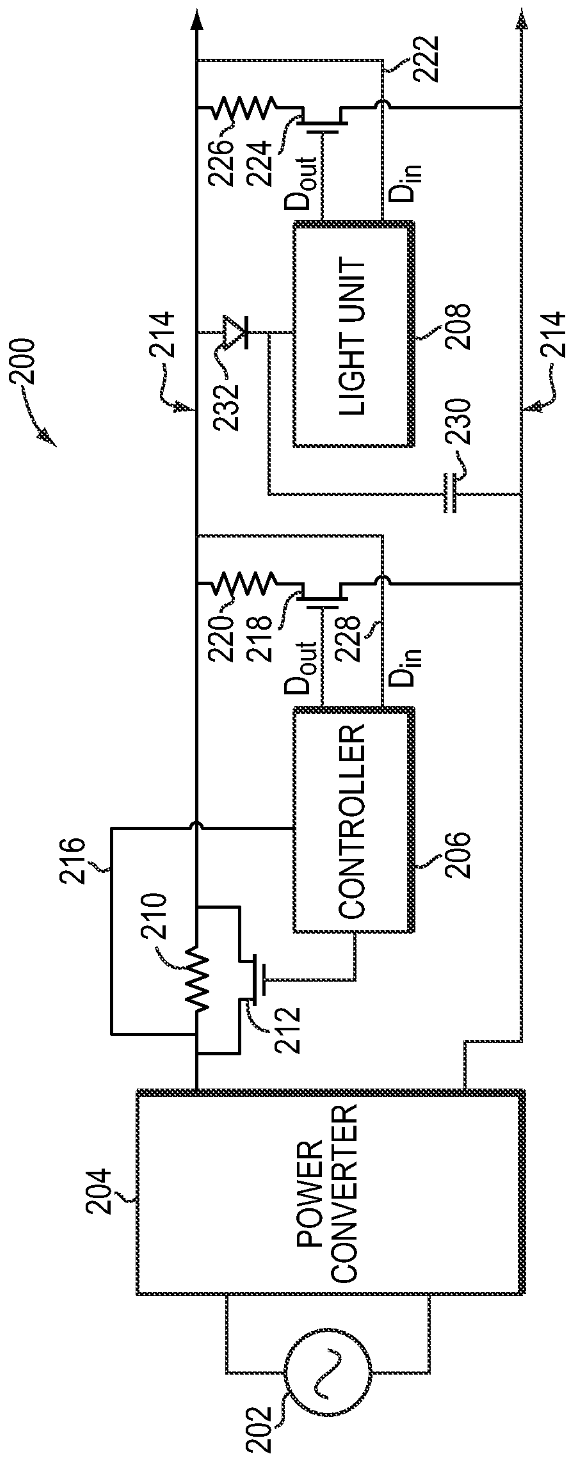

200
214
222
226
224
D_{out}
D_{in}
LIGHT UNIT
208
232
230
214
220
218
228
D_{out}
D_{in}
CONTROLLER
206
216
210
212
POWER CONVERTER
204
202

FIG. 2A

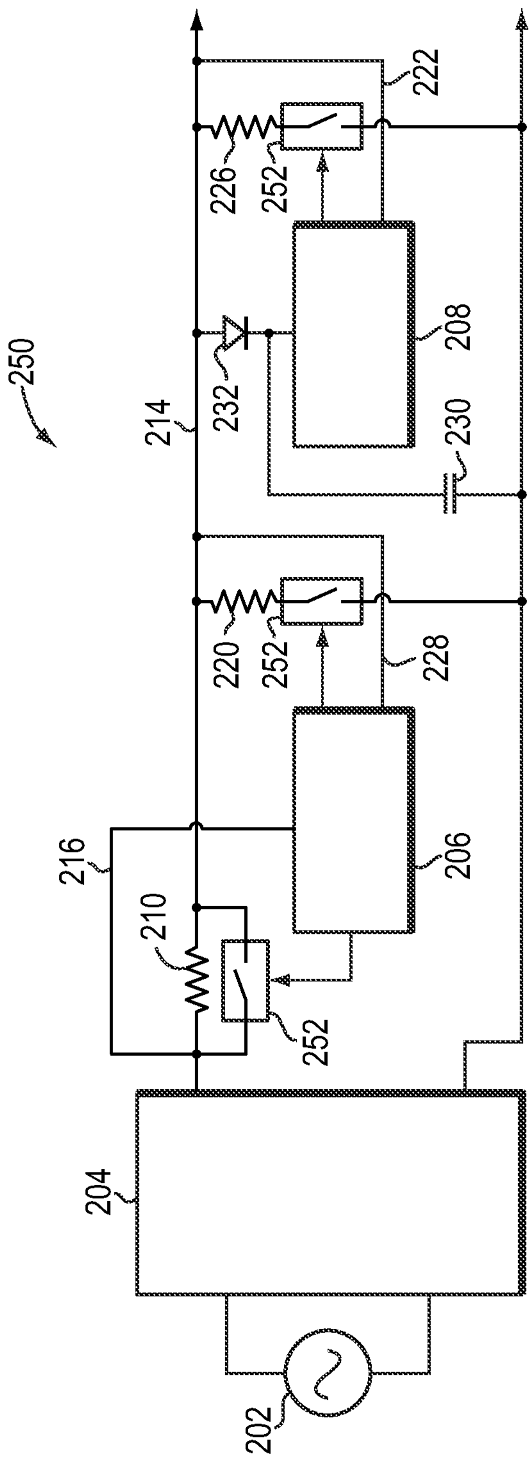
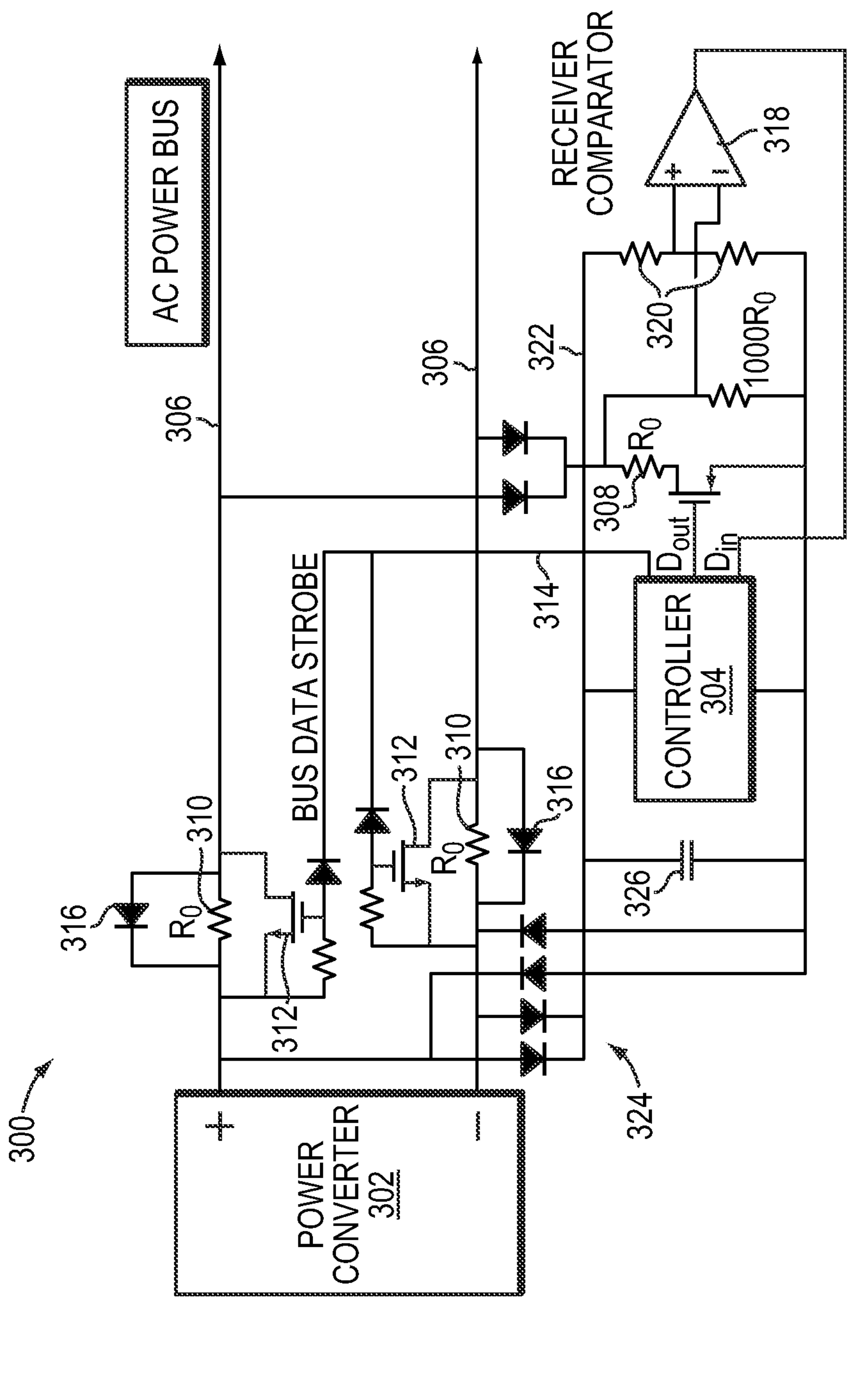
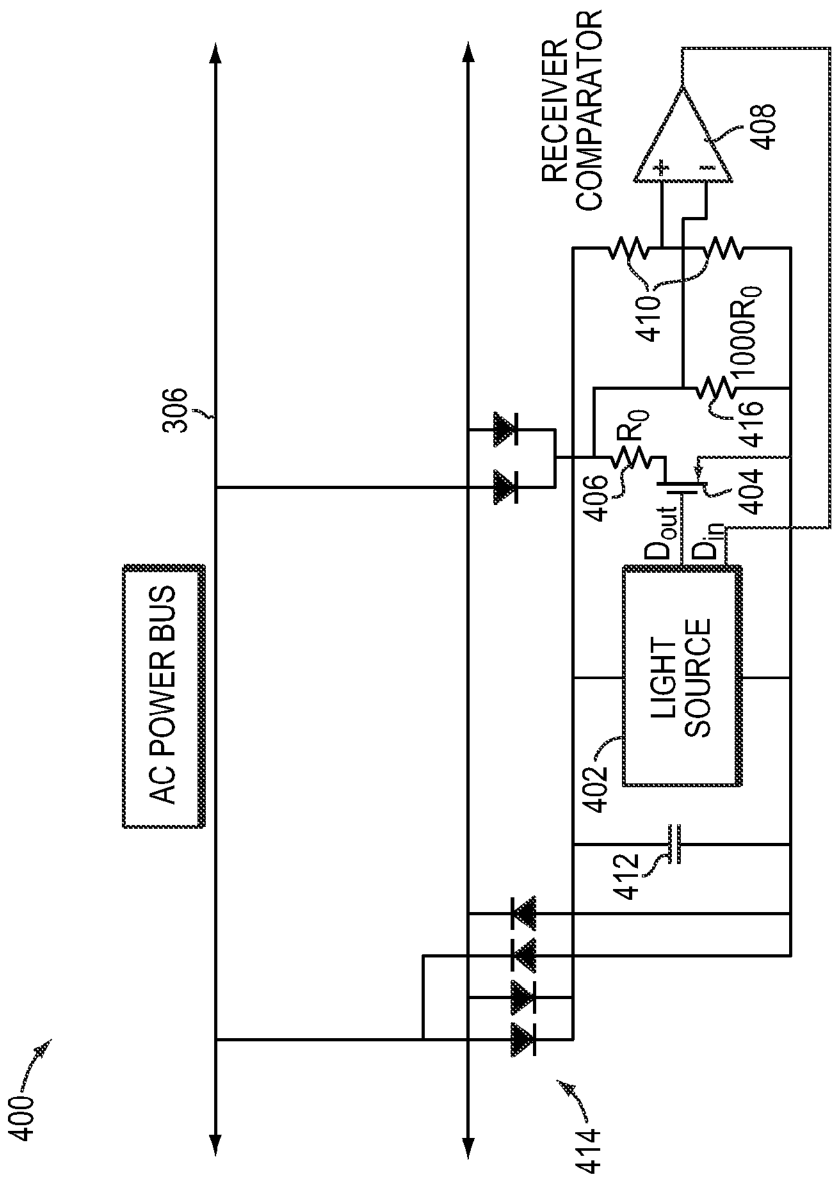

250
214
222
226
252
232
208
230
220
252
228
216
210
206
252
204
202

FIG. 2B



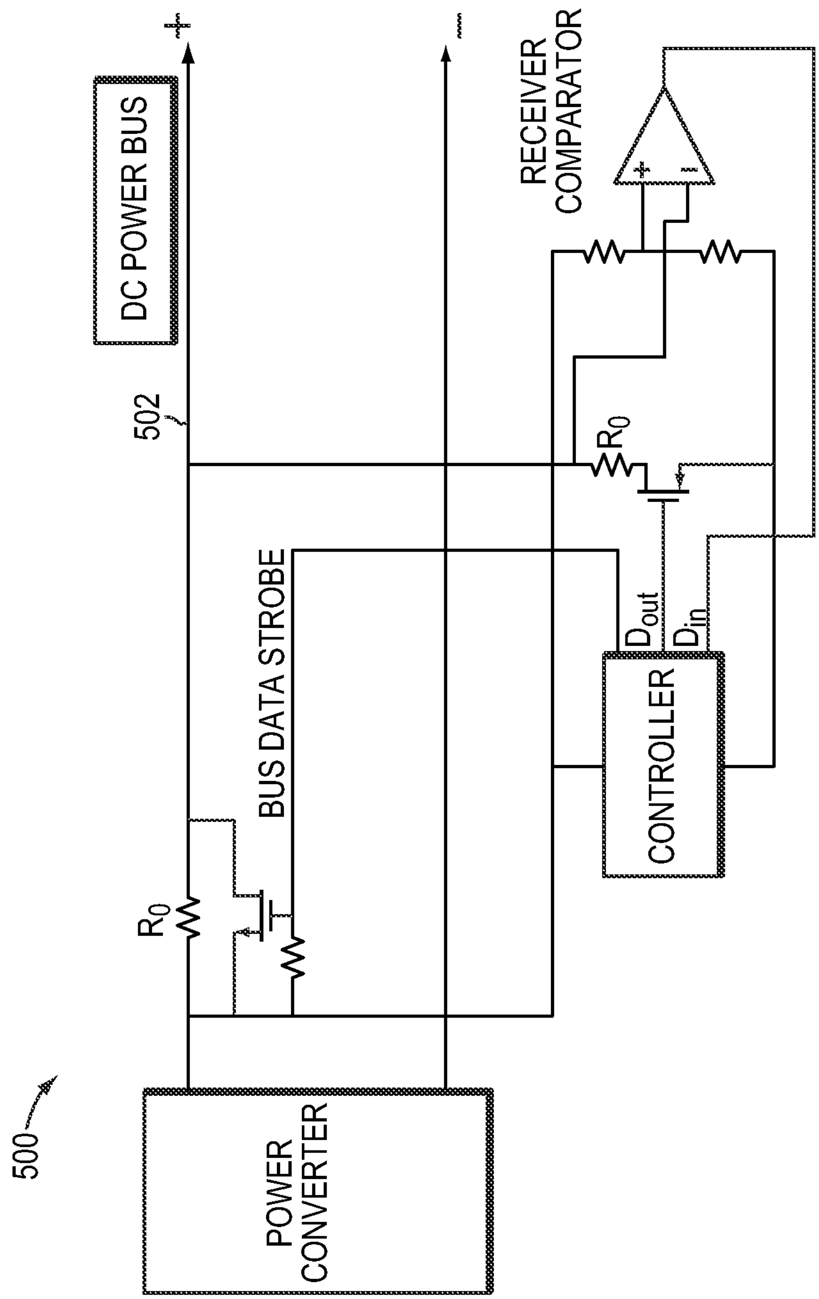
AC POWER BUS
RECEIVER COMPARATOR
318
306
306
322
320
1000R0
R0
308
Dout
Din
314
BUS DATA STROBE
CONTROLLER
304
310
312
316
326
324
300
POWER CONVERTER
302
+
−

FIG. 3



AC POWER BUS
306
RECEIVER
COMPARATOR
408
410
1000R0
R0
416
406
404
Dout
Din
LIGHT
SOURCE
402
412
400
414

FIG. 4



500
POWER CONVERTER
R0
BUS DATA STROBE
502
DC POWER BUS
+
–
R0
RECEIVER COMPARATOR
+
–
Dout
Din
CONTROLLER

FIG. 5

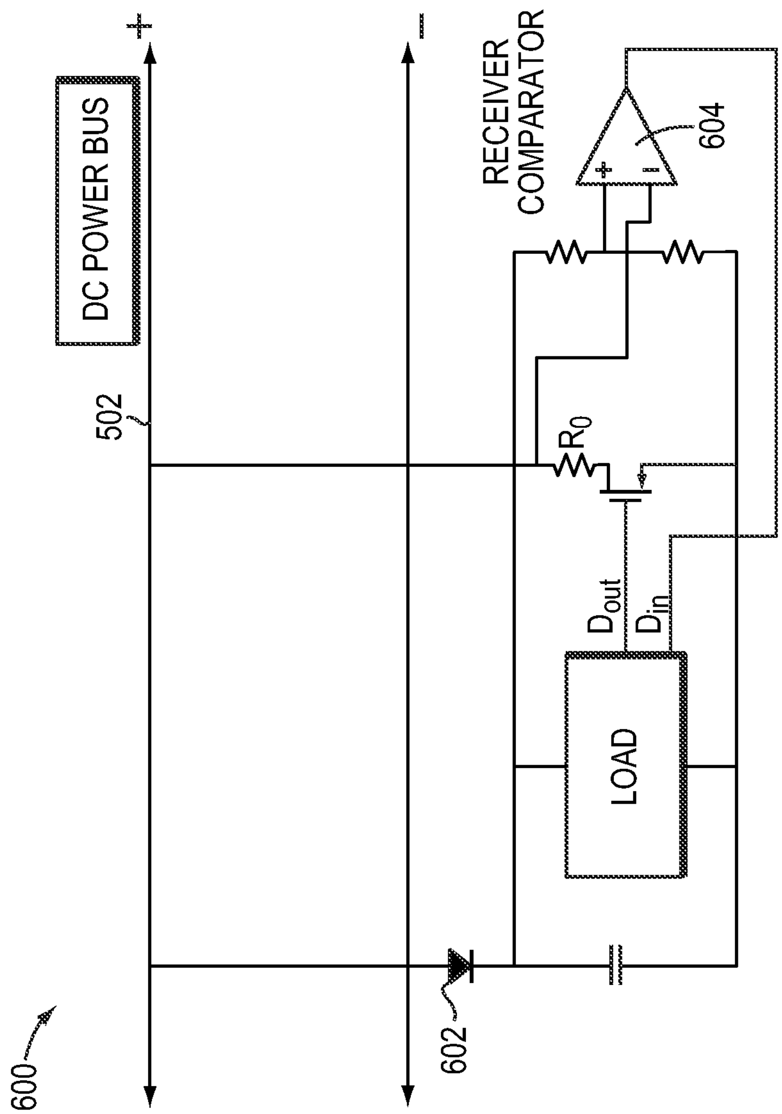

600
DC POWER BUS
+
−
502
602
R_0
RECEIVER COMPARATOR
604
+
−
D_{out}
D_{in}
LOAD

FIG. 6

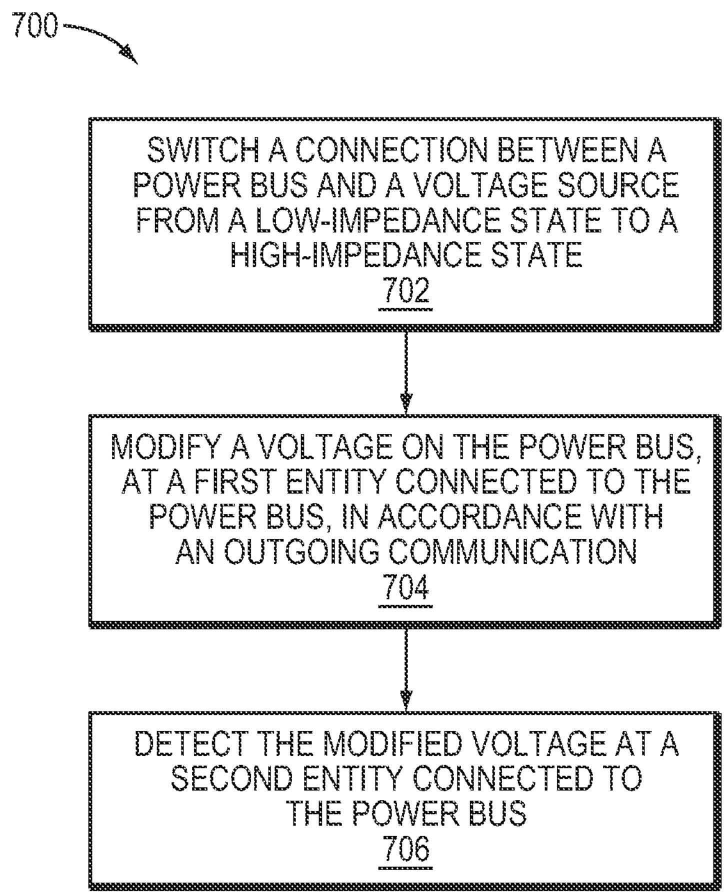

700
SWITCH A CONNECTION BETWEEN A POWER BUS AND A VOLTAGE SOURCE FROM A LOW-IMPEDANCE STATE TO A HIGH-IMPEDANCE STATE
702
MODIFY A VOLTAGE ON THE POWER BUS, AT A FIRST ENTITY CONNECTED TO THE POWER BUS, IN ACCORDANCE WITH AN OUTGOING COMMUNICATION
704
DETECT THE MODIFIED VOLTAGE AT A SECOND ENTITY CONNECTED TO THE POWER BUS
706

FIG. 7

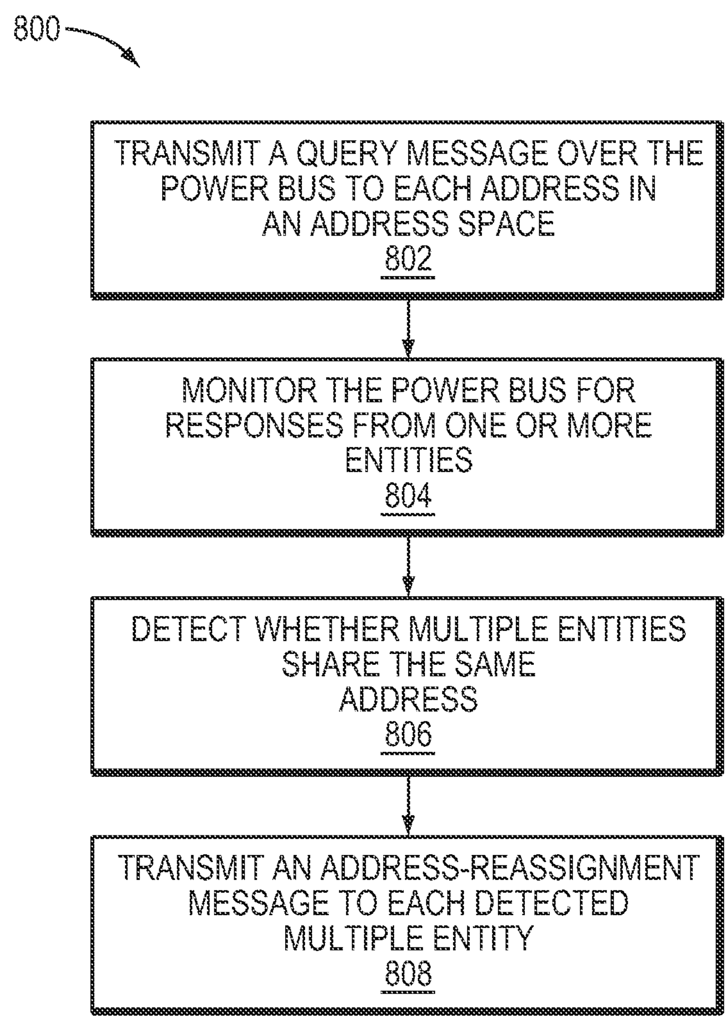

800
TRANSMIT A QUERY MESSAGE OVER THE POWER BUS TO EACH ADDRESS IN AN ADDRESS SPACE
802
MONITOR THE POWER BUS FOR RESPONSES FROM ONE OR MORE ENTITIES
804
DETECT WHETHER MULTIPLE ENTITIES SHARE THE SAME ADDRESS
806
TRANSMIT AN ADDRESS-REASSIGNMENT MESSAGE TO EACH DETECTED MULTIPLE ENTITY
808

FIG. 8

COMMUNICATION WITH LIGHTING UNITS OVER A POWER BUS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to and the benefit of U.S. Provisional Patent Application Ser. Nos. 61/383,506 and 61/383,517, both filed on Sep. 16, 2010, which are hereby incorporated herein by reference in their entirety.

TECHNICAL FIELD

Embodiments of the invention generally relate to lighting systems having a plurality of light sources that are controlled and managed by a central controller.

BACKGROUND

A lighting system that includes a plurality of light sources may locate circuitry common to all of the light sources, such as a power supply, in a central controller rather than including redundant copies of the circuitry at each light source. A central power supply, for example, may reduce the cost of the lighting system, due to the fewer total components used, as well as reduce the power consumed by the system, allow for smaller and cooler light sources, and provide a more convenient point of access for maintenance or repair. Such a system may distribute a power bus from the central controller to the plurality of light sources, which may be widely distributed across a room, building, or other area.

In addition to distributing power, the central controller may change the brightness, color, or other such property of one or more of the light sources from a single, easily accessible location. Status information, such as temperature, may be sent from the light sources to the central controller, which may automatically adjust a property of the light sources in response to the information or may present the information to a user. The commands to the lights and the information read from the lights, may be sent and received using one or more buses routed, in addition to the power bus, between the central controller and the light sources. More buses may, however, mean more cost added to the system and more difficulty in installing and maintaining the system.

In some systems, the power bus is also used as a command bus by piggybacking a high-frequency communication signal on top of the low-frequency power signal. These systems are, however, susceptible to noise and/or transmission issues, causing commands sent to the lighting units to be misinterpreted or missed and data received from the lighting units to be corrupted. Furthermore, identifying one lighting unit amongst the plurality of units connected to the central controller may be difficult or impossible, preventing individual control of a single lighting unit. This difficulty is compounded in systems where the number of lighting units is not known at the time of manufacture or installation (e.g., lighting units may be added or removed from the system during its installed lifetime) because the central controller may not be able to identify the addition or removal, causing further communication problems.

A need therefore exists for a lighting system featuring a central controller capable of communicating reliably and dynamically with any number of lighting units over a single, combined power and command bus.

SUMMARY

Various aspects of the systems and methods described herein include a lighting system having a central controller

and a plurality of light sources located remotely thereto. The central controller and each of the light sources share a common power bus. The central controller sends messages to the light sources by putting the power-supply output into a high-impedance state, thereby allowing manipulation of the power-bus voltage and varies the power-bus voltage in accordance with an outgoing communication. The light sources receive the variations and, hence, the communication encoded therein. The light sources may each have unique identifiers or addresses, so that the central controller may address each light source individually. If two light sources share the same address, the central controller may detect the sharing and send a command to the detected address to force the light sources to choose new addresses.

In one aspect, a method of communication among a plurality of entities connected to a power bus powered by a power supply includes switching a connection between the power bus and the power supply from a low-impedance state to a high-impedance state. A voltage is modified on the power bus, at a first entity connected to the power bus, in accordance with an outgoing communication. The modified voltage is detected, and the communication thereby received, at a second entity connected to the power bus.

The first entity may include a central control unit and the second entity may include a light source; the outgoing communication may include a command to modify a property of the light source. The modified voltage may be detected at an additional light source connected to the common power bus, and the communication may uniquely address the light source or the additional light source. Alternatively, the first entity may include a light source and the second entity may include a central control unit; in this case, the outgoing communication may include a status of the light source.

Modifying the voltage may include applying a negative pulse to the power bus; the negative pulse may have a voltage approximately one-half the voltage of the power supply. The connection between the power bus and the power supply may be switched, after the modified voltage is detected, from the high-impedance state to the low-impedance state. Sending the communications signal may include sending a wake-up signal and/or an entity identification signal, and the communications signal may be encoded. Receiving the communications signal may include detecting a negative pulse on the common power bus and/or placing a messaging load on the common power bus and thereafter strobing a source impedance of the power supply. The entities may include light sources, and a sufficiently constant voltage may be maintained at the light sources to avoid degradation, detectable to a human eye, of emitted light during negative-going pulses.

In another aspect, a system for communicating among a plurality of entities powered by a power supply via a power bus includes an impedance-switching circuit for selecting between a low power-supply output impedance and a high power-supply output impedance. A central controller selects, using the impedance-switching circuit, the high power-supply output impedance and thereafter sends a command over the power bus. A light source receives the command, over the power bus, from the central controller and sends a response over the power bus thereto.

The central controller may include a messaging-load impedance for applying a negative pulse to the common power bus and/or a comparator for detecting a negative pulse on the common power bus. The light source may include a messaging-load impedance for applying a negative pulse to the common power bus and/or a filter capacitor for supplying power to the light source when the high power-supply output impedance is selected. The impedance-switching circuit may include a power FET, silicon-controlled rectifier, and/or a thyristor. The power bus may be an AC or DC bus.

In another aspect, a light source, powered by a power supply via a power bus, communicates with a central controller connected to the power bus. The light source includes an LED light for emitting light and an input circuit for detecting a change in voltage on the power bus initiated by the central controller. A processor interprets the change in voltage as a command. An output circuit modifies the voltage on the power bus, thereby sending a communication to the central controller, in response to the command. A capacitor may be used to provide power to the LED light during a communication.

In another aspect, a method of assigning unique identifiers to a plurality of entities connected to a power bus includes transmitting a query message over the power bus to at least one address in an address space used by the plurality of entities. The power bus is monitored, for at least one queried address, for a response from one or more entities. Based on the response communication, the method detects whether multiple entities share the same address and causes any detected multiple entities to assume a unique address.

Causing the detected multiple entities to assume the unique address may include transmitting an address-reassignment message to each detected multiple entity. A query message may be transmitted to each address in the address space and the power bus may be monitored for every address in the address space. A new address may be generated at a detected multiple entity, and the new address may be based on a random number and/or on an available address range transmitted to the detected multiple entity. The new address may replace an old address or may be an extension of an old address. A table of available, single-occupied, and multiply-occupied addresses may be created based on the response communication. Detecting whether multiple entities share the same address may include examining an amplitude of the negative-going pulses during the response communication. The message and responses may be transmitted in a sequence of negative-going pulses on the power bus. Detecting whether multiple entities have the same address may include causing each of a plurality of entities having the same address to respond after a delay determined by random-number generation so that said entities respond separately in time.

In another aspect, a system for assigning unique identifiers to a plurality of entities connected to a power bus includes a central controller for (i) transmitting a query message over the power bus to each address in an address space, (ii) detecting responses indicative of a plurality of entities assigned to a single address, and (iii) transmitting an address-reassignment message to each of the plurality of entities. Each of the plurality of entities may include a random-number generator for generating a new address in response to the address-reassignment message and/or a read-write memory for storing its address. The central controller may include a read-write memory for storing data relating to the detected responses for each address.

These and other objects, along with advantages and features of the present invention herein disclosed, will become more apparent through reference to the following description, the accompanying drawings, and the claims. Furthermore, it is to be understood that the features of the various embodiments described herein are not mutually exclusive and can exist in various combinations and permutations.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, like reference characters generally refer to the same parts throughout the different views. In the following description, various embodiments of the present invention are described with reference to the following drawings, in which:

FIG. **1** block diagram of a central controller and a light source in accordance with an embodiment of the invention;

FIGS. **2**A and **2**B are schematic block diagrams of communication ports in accordance with embodiments of the invention;

FIGS. **3** and **4** are schematic block diagrams of an interface with an AC power bus in accordance with embodiments of the invention;

FIGS. **5** and **6** are schematic block diagrams of an interface with a DC power bus in accordance with embodiments of the invention;

FIG. **7** is a flowchart of a method for communicating among entities on a shared power bus in accordance with an embodiment of the invention; and

FIG. **8** is a flowchart of a method for detecting and reassigning addresses for entities initially assigned the same address in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

FIG. **1** is a block diagram of a lighting system **100** implemented in accordance with embodiments of the present invention. An AC source **102** (e.g., a household wall socket or other suitable power supply) provides power to a power converter **104**, which transforms the input power into a form suitable for powering a light source **106**. Only one light source **106** is shown, but the system is capable of supporting a plurality of light sources **106** up to a maximum number supported by the maximum power output of the power converter **104**. The converted power may be AC or DC power, in accordance with the requirements of particular applications and is distributed by a power bus **108**. A central controller **110** communicates with the one or more light sources **106** using the power bus **108**; the central controller **110** may be powered by a separate supply link **112**, by the power bus **108**, or by any other means. Communication ports **114**, **116** may be used by the central controller **110** and light source **106**, respectively, to interface with the power bus **108**. A switch **118**, disposed in series between the power converter **104** and the power bus **108**, may be configured in either a low-impedance or high-impedance state, as determined by, e.g., the central controller **110**. As explained in greater detail below, the switch **118** may be temporarily placed in a high-impedance state to allow communications among the central controller **110** and the light source **106** using the power bus **108**. The light source **106** may have a unique address that allows the central controller **110** to designate it as the sole recipient or source of commands or data, respectively, even if additional light sources **106** are connected to the power bus **108**.

Any voltage or frequency may be used by the power converter **104** to supply power to the light source **106** via the power bus **108**, and the present invention is not limited to any particular voltage or frequency. Example voltages for the power bus **108** include 12 and 24 V, and example frequencies include 0, 50, 60, or 400 Hz. In one embodiment, the power bus **108** is a low-voltage bus, thereby increasing the safety in distributing power to the light source **106**. The power converter **104** may include a voltage regulator (or similar circuit), thereby providing a reliable supply level to a variable number of light sources **106** (e.g., from one to five, ten, twenty, or more light sources **106**).

In one embodiment, communications over the power bus **108** are initiated by the central controller **110**. The switch **118** may be switched from a low-impedance (or "power mode") to a high-impedance (or "messaging mode") state by the central controller **110** to initiate communications. The central controller may include a digital processor (e.g., an ASIC, digital-signal processor, microcontroller, microprocessor, or other similar device) and/or analog circuitry to interface with the rest of the components in the system **112**. An input/output interface may be used to receive commands from and/or send information to a user (via, for example, a USB, Ethernet, wireless, or other similar port). The central controller **110** may be used to turn the light source **106** on and off and/or set the dimming level of the light source **106** via the commands. Other commands from the central controller **110** may be used to configure the lighting system, calibrate the lights and/or measure LED junction temperature for thermal management. The central controller **110** may also include conventional on-board self-test, analysis, and configuration circuitry or algorithms to, for example, detect an over-temperature condition in the light source **106** and automatically reduce the brightness of the light source in response.

As described in greater detail below, a variety of addressing schemes may be used for two-way communication between the central controller and the light source **106**. In one embodiment, the central controller **110** communicates with the light source **106** and requests a response therefrom. The central controller **110** then allots a communication response window, during which the central controller **110** is idle with respect to the power bus **108**, to allow the light source **106** control of the power bus **108** (i.e., the light source **106** is allowed access to the power bus **108** and may vary the voltage of the power bus **108**).

The light source **106** may be a module that includes a microprocessor, LED, LED driver, and/or a communication port **116**, connected to the power bus **108**. The power supplied to the central controller **110** from the power converter **104** may be separate from the power bus (via, e.g., the link **112**) in order to allow the power bus **108** to be switched off while maintaining the power link **112** to the central controller **110**. In the light source **106**, the microprocessor may regulate the LED current and communicate with the central controller **110** via the power bus **108**. The light source **106** may further include DC loads connected to the power bus **108** by rectifiers and/or capacitors for disconnecting the loads from the power bus **108** when the bus **108** is in message mode. The light source **106** may use buck, boost, or combination buck/boost driver circuits for the LEDs therein, depending on available bus voltage and required light voltage. The current invention is not, however, limited to any particular method of powering LEDs, and any system or method known in the art is within the scope of the present invention. The number of light sources **106** in the system **100** determines, at least in part, the total current in the power bus **108**; the bus conductor size is selected accordingly to provide an acceptable distribution voltage drop.

One implementation **200** of a lighting system in accordance with embodiments of the current invention is illustrated in FIG. **2**A. An AC source **202**, power converter **204**, central controller **206**, communications port circuitry and light source **208** are disposed in the system **200** as described above with reference to FIG. **1**. The switch **118** is implemented using a source load **210** and a field-effect transistor ("FET") **212**, the gate terminal of which is controlled by the central controller **206**. When an appropriate voltage is applied to the gate of the FET **212** so that a channel forms in the FET between its source and drain, power flows from the power converter **204** to the power bus **214** via the low-impedance path provided by the channel of the FET **212**. When the gate voltage of the FET **212** is adjusted such that the FET **212** transitions to a high-impedance state, the source load **210** partially isolates the power converter **204** from the power bus **214**, allowing manipulation of the voltage on the power bus **214** in accordance with the communications system described herein. Any type of voltage- or current-controlled switching device may be used, however, and the current invention is not limited to only a switch based on the FET **212**. FIG. **2**B illustrates, for example, an embodiment **250** using generic switches **252**. Power may be supplied to the central controller **206** via a link **216** on the power-converter side of the source load **210** so that power to the central controller **206** is not interrupted by the turning off of the FET **212**.

In one embodiment, communication between the central controller **206** and the light source **208** is accomplished by pulling down the voltage on the power bus **214** (e.g., to approximately half the normal DC power voltage) for short durations, i.e., imposing negative pulses onto the power bus **214**. The controller **206** may apply a negative pulse to the power bus **214** by activating a second FET **218** to switch in a communication load **220** across the lines of the bus **214**. An input port **222** on the light source **208** detects the negative pulses. The light source **208** may similarly assert a negative pulse on the power bus **214** using a FET **224** and communication load **226**, and the central controller **206** may detect the pulse at an input port **228**.

When the power bus **214** is in message mode (i.e., the FET **212** is switched off and the power converter is separated from the power bus **214** by the source load **210**), the light output by the light source **208** may be affected by the variations on the power bus **214**. A capacitor **230** may be used to store charge to maintain an LED drive voltage appropriate for the light source **208** during the communication pulses. A diode **232** may be used to isolate the capacitor **230** from lower voltages on the power bus **214** and prevent charge from being siphoned off thereto and affecting message transmission.

The signaling pulses on the power bus **214** may be short-duration negative pulses having duration of approximately 10 μsec, during which time the light source **208** is powered by the capacitor **230**. The pulses may be varied in terms of width and interval, or may be of a single width, having a consistent interval between pulses. As described in more detail below, the light source **208** monitors incoming pulses for information encoded in their width, interval, presence, or other attribute and interprets commands based on the received pulses.

In one embodiment, the communication loads **220**, **226** are equivalent to the output impedance (i.e., the small internal resistance of the power converter **204** and the relatively larger resistance of the resistor **210**) of the power converter **204**, thereby producing negative pulses having an amplitude of half the DC power voltage output by the power converter **204**. In one embodiment, the central controller **206** and light source **208** receive data from the power bus **214**, via the input ports **228**, **222**, using a comparator having an appropriate threshold between the high and low amplitudes of the bus communication voltages. Lower-amplitude communication pulses may be desirable for electromagnetic compatibility and may be implemented by providing the communication loads **220**, **226** with a higher resistor value than the source load **210**.

FIG. **3** illustrates another embodiment **300** of a power converter **302**, central controller **304**, and associated communications port circuitry that is, in this case, configured as a message initiator for communicating over an AC power bus **306**. Messages may be placed on the power bus **306** by loading the bus with a messaging load **308** and switching the power converter source impedance **310** from low to high impedance, thereby switching the bus **306** from power to messaging mode. The messaging load impedance **308** and source impedance **310** may be matched (i.e., equal) and may each have a value of approximately 200 ohms. Thus, when both loads **308**, **310** are enabled, the bus voltage is reduced to approximately half of its nominal, power-mode voltage. With only the messaging load **310** present, the bus voltage remains at nominal voltage until the messaging load **308** is introduced.

The central controller **304** switches or strobes the source load **310** to the messaging load **308**, by manipulating the gate voltage of the FETs **312**, for short time intervals to produce a signaling pulse on the power bus **306**. To place the bus **306** in power mode, the central controller **304** holds a bus-data-strobe signal **314** low, which provides a gate turn-on voltage to the two power FETs **312** that bypass the source loads **310** at the output of the power converter **302**. Although two source loads **310** are provided for an AC supply, only one at a time is inserted for messaging, depending on the polarity of the power supply voltage at the time the messaging pulses are introduced. When the data-bus-strobe signal **314** is low, the FET **312** on the positive side of the supply **302** conducts, as does the diode **316** on the negative supply side. When a message pulse is introduced, the data-bus-strobe signal **314** is asserted high, thereby turning off the high-side power FET **312** and inserting the source load **310**. When a messaging load **308** is present at the time the strobe signal is asserted, the bus voltage drops to half the bus voltage immediately prior to the messaging mode.

The system **300** may also be configured to receive communication pulses from, e.g., light sources connected to the power bus **306**. In this case, the central controller **304** holds the bus-data-strobe signal **314** low, as described above, but does not assert the messaging load **308**. The power bus voltage is applied to the input of a comparator **318**, which compares the bus voltage to a reference value (generated by, for example, a resistor divider **320**). The impedance ratio of the resistors in the resistor divider **320**, and the reference value generated thereby, may be determined by the ratios of the impedances of the source and messaging loads **310**, **308**. Once a light source places a negative pulse on the power bus **306**, the voltage on the bus **306** falls below the reference voltage, and the comparator **318** registers this change by sending a command signal to the central controller **304**. Any method known in the art of detecting a voltage level may be used to detect the presence of a pulse on the power bus **306**, however, and the current invention is not limited to use of a comparator. In one embodiment, different voltage levels on the power bus **306** correspond to different bits of binary information.

The central controller **304**, which may include digital logic, may be powered by a local DC power bus **322**. The DC voltage on the local bus **322** may be generated from the AC output of the power converter using, for example, a diode rectifier **324** and a filter capacitor **326**. The local bus **322** may also be used to supply power to the resistor divider **320**, or for any other component or system that requires DC power.

In other embodiments, devices other than the power FETs **312** are used for switching the bus **306** between power and messaging modes. One example of such a device is a gate turn-off thyristor, which may be turned off by a gate signal before zero-conduction current is reached. Another device is a silicon-controlled rectifier or standard thyristor operated using a high-frequency AC supply. At a high AC supply frequency, for example 100 KHz, the bus **306** may be switched to communication mode for the duration of a first AC half-cycle and returned to power mode on the next AC half-cycle. Using such switching methods, a single messaging-load resistor may be used. The present invention is not limited to any particular implementation of bus-switching circuit, however, and any equivalent circuits are within the scope of the present invention.

The nominal voltage on the power bus **306** may determine the message signal amplitude. In one embodiment, for the AC power bus case, messaging pulses are placed on the bus **306** only when the bus voltage is greater than a minimum value. The central controller **304** may monitor the bus voltage to assure that the bus minimum voltage is exceeded before beginning a message sequence.

FIG. **4** illustrates an embodiment **400** of a light source **402** and associated communications circuitry configured for communicating over the AC power bus **306**. Like the central controller **304**, the light source **402** places a pulse on the power bus **306** by asserting a FET **404**, thereby pulling the voltage on the power bus **306** down through a message load **406**. The light source may receive incoming pulses by monitoring the voltage on the power bus **304** with a comparator **408**, which compares the power bus voltage to a reference voltage generated by a resistive divider **410**.

When the bus **306** is placed in messaging mode by the central controller **304** (by, e.g., strobing the bus data signal **314**), the power converter **302** no longer provides current for the light source **402**. Instead, power is provided by one or more filter capacitors **412**. In messaging mode, the bus voltage drops until the rectifiers **414** that connect the light source **402** and filter capacitor **412** to the bus **306** stop conducting as the forward-biased junction voltage is reduced. The bus voltage drops further due to the loads presented by the receiver comparator input circuits **410** and the messaging load **406**, if asserted. A comparator input resistor **416** is sized at approximately 1000 times the size of the messaging load **406** to assure a low bus voltage is placed at the comparator **408** without significantly loading the bus **306** when multiple loads (i.e., multiple light sources **402**) are present. The resistor **416** discharges parasitic capacitance on the bus **306** and receiver input circuit **410** to assure the messaging bus voltage is presented to the comparator **408**.

In one embodiment, the responder messaging pulses are placed on the power bus **306** by action of both central controller **304** and light source **402**. The central controller **304** strobes the source messaging impedance **314** while the light source **402** has placed (or not placed) a messaging load **406** on the bus **306** to produce a responder message pulse (or lack of pulse). The light source **402** may place the message load **406** on the bus before the strobe occurs; the light source **402** may detect when the strobe occurs by means of a communication clock synchronized to an initiator frame.

FIGS. **5** and **6** illustrate central-controller **500** and light-source **600** circuits, respectively, for a DC power bus implementation. The modification to the central controller **500** for the DC bus **502** removes one power-converter messaging source impedance, one bypass-power FET, and the full-wave rectifiers for the messaging initiator and its receiver comparator. For the light source of FIG. **6**, the full-wave rectifier for the load is replaced by a single diode **602**, and the receiver comparator **604** is directly connected to the positive bus conductor **502**. The comparator input resistor may be eliminated.

A method of using an embodiment of the current invention, in accordance with the implementations described above, appears in a flowchart **700** in FIG. **7**. With reference also to FIG. **2A**, in a first step **702**, a connection between the power bus **214** and the voltage source **204** is switched from a low-impedance state to a high-impedance state (using, for example, the FET **212**). In a second step **704**, a voltage on the power bus **214** is modified at a first entity connected to the power bus, in accordance with an outgoing communication. For example, the central controller **206** may pull down the voltage on the power bus **214** using the FET **218** and the resistor **220**; in another embodiment, the light unit **208** sends a communication by pulling down the power bus with FET **224** and resistor **226**. In a third step **706**, the modified voltage is detected at a second entity connected to the power bus (e.g. the central controller **206** or the light unit **208**, using the input ports **228**, **222**), thereby receiving the communication at the second entity.

When multiple light sources are present in a system, as is often the case, the central controller may need to uniquely identify one of the light sources, determine how many light sources are present, or identify which light source is sending incoming data. Each lighting unit may thus be assigned a unique identifier. When a light source detects, on the power bus, a sequence of pulses corresponding to its identifier, the selected lighting unit may "wake up" in response, in the manner of, for example, a network node responding to a MAC address on a local area network.

In one embodiment, a plurality of light units is each provided with a unique address to allow the central controller to select a particular light source as a recipient of a message. A complete message may include an initiator frame followed by a responder frame. The initiator frame may include a plurality (e.g., four) of fields, such as wake-up, address, command and data fields. The responder frame may include a preamble field and data field. The response frame may be a special field used for address map queries by the initiator. In this embodiment, the response field may be a single long-duration pulse or a single short-duration pulse.

The wake-up field of the communication frame includes a sequence of pulses that identifies the start of a message and provides synchronization to a data clock. The rest of the message may be encoded to maintain self-clocking of the data in the message, as is known in the art, which may assist clock recovery and/or detection at the receiver. Embodiments of the invention may use, but are not limited to, non-return-to-zero ("NRZ") or Manchester transmission protocols. Following the initiator frame, a responder frame is transmitted onto the data bus. The responder frame, sent by the responder, may be assisted by the initiator, which further provides bus data strobes to clock the data onto the bus while the responder controls the messaging load on the bus. The strobe clock continues at the nominal frequency while the responder switches the communication impedance onto the bus and monitors the bus for the expected data pulses.

As noted above, to establish communication and provide thermal management of the lighting units, the central controller may identify and address each lighting unit uniquely. When the lighting system is first installed, or when a lighting unit is added to a system, it is likely that several lighting units have the same communication address. Various approaches to detecting this condition and reassigning addresses are described below.

The lighting units typically have non-volatile memory registers (e.g., electrically erasable programmable read-only memory, or EEPROMs) for storing address information. If non-volatile memory is not provided, then the central controller may reconfigure the lighting units after each power-on cycle. Non-volatile memory allows for monitoring of light-source usage history and its environment, which enables failure prediction for enhanced system reliability. During address configuration, the lighting units may be turned on with a nominal light output setting until configuration is complete. This action may be accomplished using, for example, a global command for turning on the lights.

In one embodiment, an eight-bit address register is used; this register may support up to 255 unique lighting units and, optionally, a reserved address. Registers of any size may be used to support any number of lights, however and the current invention is not limited to any particular register size.

A communication protocol for the lighting system may involve the central controller beginning a communication interval by sending a prescribed set of pulses onto the power bus as a wake-up signal. After the wake-up signal completes, a target address, a command code, and/or optional datafield may be sent by the central controller over the bus; and the command code and/or datafield are recognized by the lighting unit having the target address. Following a send-time interval (to allow for, e.g., the wake-up, address, command, and data fields), the addressed lighting unit may respond by imposing onto the power bus a pulse sequence corresponding to a response code and optional data, which are received by the central controller during a response-time interval. This sequence—the send-time interval and the response-time interval—completes one communication interval. Global commands to all the lighting units may be identified by sending the reserved address instead of a target address.

In one embodiment, to configure unique addresses for each lighting unit, an address occupation map is created for the lighting units in the system. The address occupation map may be arranged as a table or database stored in non-volatile memory of the central controller, and lists the available addresses with the status of unoccupied, single-occupied, or multiple-occupied lighting unit addresses. To populate this table, a query command is sent over the power bus to each of the 255 available addresses requesting a response pulse. For this command, the duration of the response pulse is sufficiently long that multiple lighting units with the same address may simultaneously load the power bus. The central controller can identify if none, one or multiple lighting units occupy the sent address by examining the amplitude of the negative pulse during the response. No lighting unit at the queried address is indicated by no response; one light at the address is indicated by a nominal pulse amplitude; and multiple lighting units are indicated by a larger-than-nominal (lower absolute voltage) pulse. The central controller scans all 255 addresses to build the address occupation map; multiple occupied addresses are reassigned among unoccupied addresses as described below.

In another embodiment, random time delays may be used for the responses to the address-query command in order to separate the responses in time. In this embodiment, each lighting unit at the queried address responds after a random time delay, which is determined by a random-number generator in the lighting unit, and the central controller counts the number of responses for each queried address. The random-number generator may base its output on any available digital or analog signal containing sufficient noise; examples include the analog-to-digital converters for measuring LED current sense voltage or other voltages, the commanded LED current in a closed-loop current regulator, or any other digital or analog signal containing noise. The least-significant bits that are dependent on noise are selected to provide the random number. The random time delay is provided by a time-interval counter preset with the random number. After the random time delay, the lighting unit responds by applying pulses to the power bus if no other lighting unit is currently responding. If another lighting unit's response is in progress, as determined by the current state of the power bus, the lighting unit further delays its response, thereby ensuring that simultaneous responses do not occur. The absence of a response indicates that the queried address is unassigned; one lighting unit at the address is indicated by one response; and multiple lighting units are indicated by more than one response. The central controller may store this information for the queried address and scan all 255 addresses to complete the table.

In one embodiment, when multiple lighting units occupy an address, the central controller reassigns addresses by sending an address-reassignment command to the lighting units sharing one address, along with an available unoccupied address in the data field. Upon receiving this command, the lighting units randomly decide to assume the new address or retain the original address. This decision may be based on a random-number generator in each lighting unit; the random numbers may be generated as described above. The least-significant bit of the data word is selected to decide whether or not to assign a new address for the lighting unit. With the lighting units independently assuming one of two addresses in this random process, the central controller may then scan the two addresses and update the stored table of unoccupied, single, and multiple occupied addresses of the original address scan. The address reassignment sequence is iterated until all lighting units have been assigned unique addresses. Alternatively, the number of addresses that are randomly selected by the lighting units may be increased by using more data bits in the random number. For example, two bits provide for selection among four addresses, three bits provide eight addresses, and so on.

In another embodiment, the lighting units randomly select address extensions to assign themselves unique addresses. In this approach, the lighting units that share a common address are commanded by the central controller to randomly select a number in a predetermined range as an address extension to their base addresses. A random number generator, as described above, may be used to select the address extension, which is the required number of least-significant bits of a noisy digital signal. An example of the range of numbers for the address extension is 0 to 15 (in hexadecimal, 0x0 to 0xF) defined by a 4-bit binary number, but any convenient range may be used. To address a light source by its address plus address extension, the base address is sent with a command defined for an address extension followed by the address extension in the data field. In this way, the central controller scans the sixteen (e.g.) address extensions at the shared address to create a list of single-occupied extensions and multiple-occupied extensions. Both the single- and multiple-occupied extensions may be reassigned available unique base addresses, and the original table of unoccupied, single-, and multiple-occupied addresses is updated with this change. In sequence, all multiple occupied addresses are commanded to randomly select new address extensions, then scanned and reassigned new unoccupied addresses and the occupation table updated. This process may proceed through all multiple-occupied addresses until all lighting units are reassigned unique addresses.

In some embodiments, addresses may be manually assigned. This approach may be advantageous, for example, when one or more lighting units are added or replaced in the lighting system. This approach ensures that usage and temperature history data for the lighting units, stored in, e.g., non-volatile storage in the central controller, remains valid when the system is serviced or altered by adding or replacing lighting units. One implementation uses a polling scheme for the central controller to query the lighting units for a system change status. The lighting units are each provided with a non-volatile memory location (e.g., one or more data bits in EEPROM), which is set during manufacturing to indicate that the lighting unit has not been configured. This memory location may also be set manually, after a service procedure, to indicate that the lighting unit requires address configuration and possibly other procedures for tracking usage history. A switch may be provided on the lighting unit to manually set the EEPROM to request configuration.

The central controller may poll the lighting units with a command to the reserved common or global address. Any lighting units with the condition set in EEPROM indicating an unconfigured status may respond to this poll. If there is a response to the poll, the central controller assigns an available unused address to the responding lighting unit or units, which then reset the EEPROM condition to indicate that configuration is no longer needed. The central controller proceeds through the above-described procedures to assign unique addresses if multiple lighting units share the newly assigned address. The polling command may be issued periodically by the central controller, or it may be initiated by the service person by operating a switch on the controller.

One embodiment of a method for assigning unique identifiers to a plurality of entities (e.g., light sources) connected to the power bus is shown in FIG. **8**. In a first step **802**, a query message is transmitted over the power bus to each address in an address space used by the plurality of entities. In a second step **804**, the power bus is monitored (by, e.g., the central controller), for each queried address, for a response from one or more entities. In a third step **806**, whether multiple entities share the same address is detected based on the response communication. In one embodiment, the central controller determines whether zero, one, or more than one light sources are assigned the address by monitoring the level of the voltage on the power bus, as described above. In a fourth step **808**, an address-reassignment message is transmitted (e.g., by the central controller) to each detected multiple entity.

It should also be noted that embodiments of the present invention may be provided as one or more computer-readable programs embodied on or in one or more articles of manufacture. The article of manufacture may be any suitable hardware apparatus, such as, for example, a floppy disk, a hard disk, a CD ROM, a CD-RW, a CD-R, a DVD ROM, a DVD-RW, a DVD-R, a flash memory card, a PROM, a RAM, a ROM, or a magnetic tape. In general, the computer-readable programs may be implemented in any programming language. Some examples of languages that may be used include C, C++, or JAVA. The software programs may be further translated into machine language or virtual machine instructions and stored in a program file in that form. The program file may then be stored on or in one or more of the articles of manufacture.

Certain embodiments of the present invention were described above. It is, however, expressly noted that the present invention is not limited to those embodiments, but rather the intention is that additions and modifications to what was expressly described herein are also included within the scope of the invention. Moreover, it is to be understood that the features of the various embodiments described herein were not mutually exclusive and can exist in various combinations and permutations, even if such combinations or permutations were not made express herein, without departing from the spirit and scope of the invention. In fact, variations, modifications, and other implementations of what was described herein will occur to those of ordinary skill in the art without departing from the spirit and the scope of the invention. As such, the invention is not to be defined only by the preceding illustrative description.

What is claimed is:

1. A method of communication among a plurality of entities connected to a power bus powered by a power supply having a power supply voltage, the method comprising:

switching a connection between the power bus and the power supply from a low-impedance state to a high-impedance state by inserting a source load between the power bus and the power supply;

modifying a voltage on the power bus such that the modified voltage is less than the power supply voltage but greater than zero in accordance with the impedance ratio of the source load and a messaging load, at a first entity connected to the power bus, in accordance with an outgoing communication, by inserting the messaging load between the power bus and ground such that the source load and messaging load divide the power supply voltage on the power bus; and

detecting the modified voltage at a second entity connected to the power bus, thereby receiving the communication at the second entity.

2. The method of claim **1**, wherein the first entity comprises a central control unit and the second entity comprises a light source.

3. The method of claim **2**, wherein the outgoing communication comprises a command to modify a property of the light source.

4. The method of claim **2**, further comprising detecting the modified voltage at an additional light source connected to the common power bus.

5. The method of claim **4**, wherein the communication uniquely addresses one of the light source or the additional light source.

6. The method of claim **1**, wherein the first entity comprises a light source and the second entity comprises a central control unit.

7. The method of claim **6**, wherein the outgoing communication comprises a status of the light source.

8. The method of claim **1**, further comprising, after detecting the modified voltage, switching the connection between the power bus and the power supply from the high-impedance state to the low-impedance state.

9. The method of claim **1**, wherein sending the communications signal comprises sending a wake-up signal.

10. The method of claim **1**, further comprising encoding the communications signal.

11. The method of claim **1**, wherein sending the communications signal comprises sending an entity identification signal.

12. The method of claim **1**, wherein the entities include light sources, and further comprising the step of maintaining a sufficiently constant voltage at the light sources to avoid degradation, detectable to a human eye, of emitted light during negative-going pulses.

13. A system for communicating among a plurality of entities powered by a power supply having a power supply voltage via a power bus, the system comprising:

an impedance-switching circuit electrically connected between the power supply and the power bus for selecting between a power-supply output impedance and a source load, the source load having an impedance higher than the power-supply output impedance;

a central controller for selecting, using the impedance-switching circuit, the source load to thereby place the power bus in a command mode and, thereafter, sending a command over the power bus by inserting a messaging load between the power bus and ground to thereby modify a voltage on the power bus to be less than the power supply voltage but greater than zero in accordance with the impedance ratio of the source load and a messaging load such that the source load and messaging load divide the power supply voltage on the power bus; and

a light source for receiving the command, over the power bus, from the central controller and sending a response over the power bus thereto.

14. The system of claim **13**, wherein the central controller comprises a comparator for detecting a negative pulse on the common power bus.

15. The system of claim **13**, wherein the power bus is one of a DC bus or an AC bus.

16. The method of claim **1**, wherein a resistance of the source load is approximately equal to a resistance of the messaging load and the modified voltage is approximately one-half of the power supply voltage.

17. The system of claim **13**, wherein the messaging load has a resistance approximately equal to a resistance of the source load and the modified voltage on the power bus is approximately one-half of the power supply voltage.

18. The method of claim **1**, further comprising receiving a communication from the second entity by (i) modifying the voltage on the power bus such that the modified voltage is the power supply voltage; (ii) at the second entity, modifying the voltage on the power bus such that the modified voltage is less than the power supply voltage but greater than zero in accordance with the impedance ratio of the source impedance and a second messaging load at the second entity, and (iii) detecting the voltage modified by the second entity.

19. The system of claim **13**, wherein the light source is configured to modify the voltage on the power bus such that the modified voltage is less than the power supply voltage but greater than zero in accordance with the impedance ratio of the source impedance and a second messaging load at the light source, and wherein the central controller detects the voltage modified by the second entity.

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